Architecture

ADAPTHAUS promotes and displays core concepts of sustainability and accessibility through its design features, layout, modularity, and subsystem integration. The design provides flexibility to efficiently use the space inside the house for multipurpose activities and adapt to the occupants' needs over time.

Our design serves the current needs of the user while also incorporating provisions for future requirements. This is where the concept of modularity emerges, and the idea of an adaptable space becomes a core concept for our project. We envisioned that a college graduate could start with one module when they are single and expand to two or three modules once they have a family and kids. When their kids leave the house for college, they can reduce their square footage by renting their third module or selling it back to a homebuilder.

ADAPTHAUS, through its multidisciplinary integrated design approach, provides a novel solution apt to the needs of the client and embodies a sustainable lifestyle. Our interior design focuses on spatial efficiency by using flexible furniture to have multipurpose rooms. Adaptability and affordability were the core pillars of subsystems' design. The project is currently located in the city of Champaign, Illinois. The project's scope is the design and construction of 2 modules of the adaptable design, further designated as modules A and C.

The material development strategy seeks to incorporate durable materials that provide the house's longevity, allowing the adaptation of modules to occur throughout the user's lifetime without compromising the project's functionality, aesthetics, and quality. To follow the premise of sustainability as a guiding principle in this project, this house's building envelope was designed as a fundamental energetic performance feature of the overall design. The envelope design is based on Champaign, IL's local climate and features continuous insulation outside the structure to alleviate thermal bridging. The R values that are achieved with the envelope design are R28 for walls, R33 for floors, and R62 for the roof. Since the wooden frame structure used in this house has a relatively high thermal conductivity, continuous insulation is utilized around the steel frame to reduce the risk of thermal bridging. Closed-cell spray foam insulation in the cavity between the stud's joists reduces the thickness of the continuous insulation and maximizes interior space. The continuous insulation reduces the

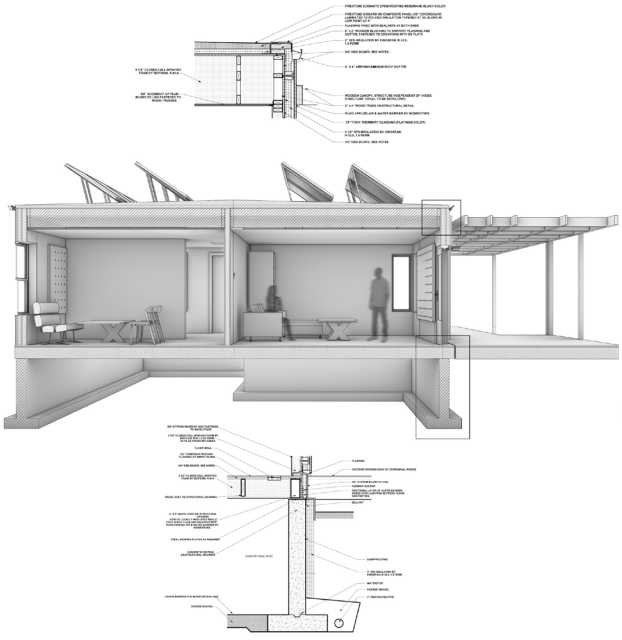

Figure 1. Envelope Sectional View of ADAPTHAUS

risk of condensation since the temperature of the interior face of the sheathing is raised above the dew point.

Water

ADAPTHAUS' water system design seeks to minimize maintenance needs while maximizing longevity, ease of installation, and water reclamation and reuse. For domestic water delivery, PEX piping was chosen over traditional materials such as copper and CPVC. PEX piping is resistant to corrosion and bursting due to freezing, therefore extending the plumbing's lifespan. Additionally, PEX is more user and maintenance-friendly than most traditional plumbing materials due to its ease and speed of installation, flexibility, and low cost.

We wanted to minimize potable water consumption for landscape irrigation through the reclamation and reuse of stormwater and greywater, which is currently under review by the Illinois Department of Public Health. Precipitation tends to fluctuate throughout the year, contributing to seasonally abnormally dry soils. Seasonal unpredictability and variability in precipitation and soil moisture in Champaign, Illinois, are likely to increase under climate change. As a result, potable water is often used as a water source for landscape irrigation. The reclamation and reuse of greywater would provide a reliable water source for subsurface irrigation, reducing the impact of variable precipitation on water consumption for landscape irrigation. The collection of stormwater in rain barrels provides a flexible and supplemental water source. In Champaign, Illinois there is an average rainfall of 41 inches annual providing a potential 30 thousand gallons of water to be collected with our rainwater collection system.

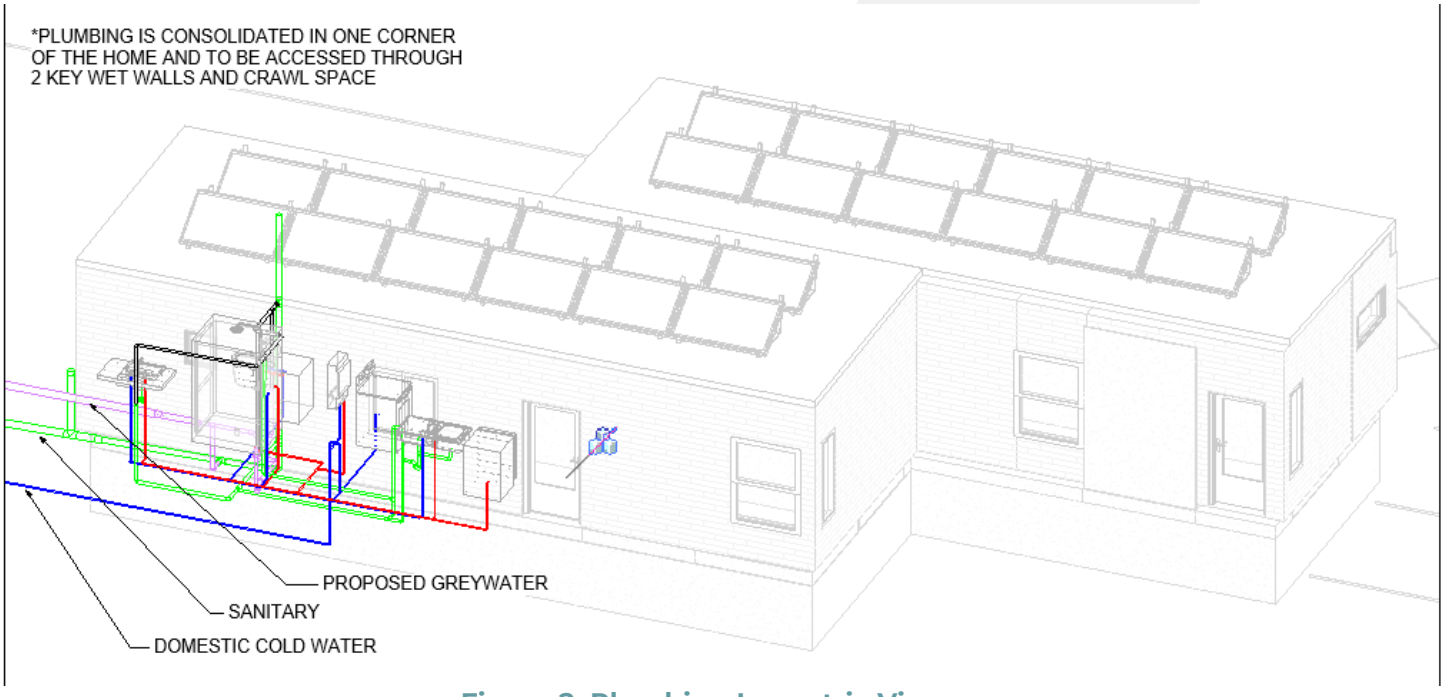

Figure 2. Plumbing Isometric View

Structure

We examined the effects of earthquake, wind, and snow load on our modules for our structure. While designing for these loads, we wanted to ensure our structure's stability for environmental extremes.

Our first line of defense is our sheathing, which doubles as a shear wall throughout our building's framing. This increases our rigidity against any lateral loads and helps carry them to the foundation.

Our second line of defense is the choice of using a Vierendeel truss design for our roof. They are considered to be a Special Truss Moment Frame (STMF) and contain a special segment that acts as a ductile "fuse". During an earthquake, high lateral forces create vertical shear forces in the truss, that when high enough, will form inelastic deformation (plastic hinges) at the ends of the top and bottom chord of the Vierendeel opening. This allows beams to fail before columns (Strong Column Weak Beam design), ensuring that the roof will deform substantially before the walls collapse (soft story failure). Putting all the walls and trusses together gives you a yielding frame structure, and the ductility inherent in this truss design has created a passive energy dissipation system by doubling as an effective damper.

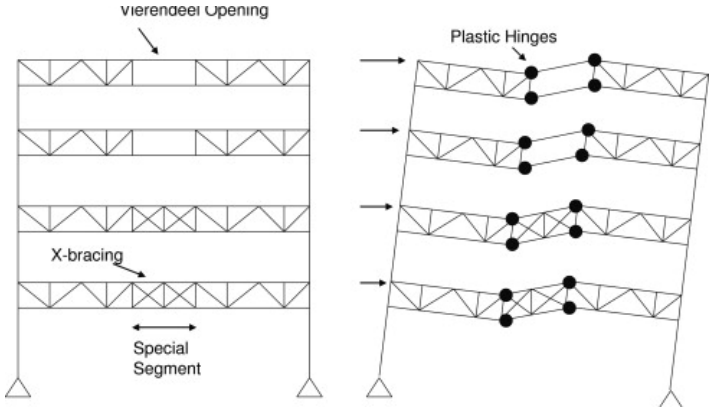

Figure 3. Plastic Hinge formation on Vierendeel trusses

From H.D. Ölmez, C. Topkaya, "A numerical study on special truss moment frames with Vierendeel openings", Journal of Constructional Steel Research, Volume 67, Issue 4, 2011, https://doi.org/10.1016/j.jcsr.2010.11.013.

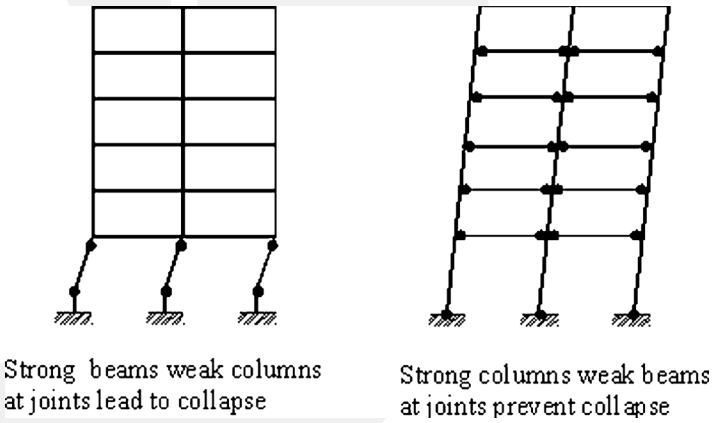

Figure 4: Strong beam weak column vs strong column weak beam design

From E. Atimay, R. Kanit, "Learning Seismic Design from the Earthquake Itself", Journal, Practice Periodical on Structural Design and Construction, Volume 11, Issue 3, 2006, https://doi.org/10.1061/(ASCE)1084-0680(2006)11:3(149)

Based on data from Applied Technology Council (ATC), we were able to find the response spectrum and parameters for seismic hazards in Champaign County. Due to our single story design and a flat roof profile, the average fundamental period of our building is 0.1167s. Earthquakes can have periods between 0.03-33 seconds, and their intensity and period vary based on how far from the epicenter you are, and the type of soil you are on, which makes them unpredictable. However, for short period structures, the best way to dissipate energy is to keep them strong and elastic. The simplicity of our design minimizes the displacement response and decreases the probability of both structural and non-structural damage to the structure. Using the assumption of a Risk-Targeted Maximum Considered Earthquake (MCE_R) ground motion value of 0.172 g with a period of 0.2 s, we find that the seismic design base shear is 0.57 kips, while in comparison, minimum wind design base shear is 11.34 kips.

Our building is designed to withstand wind speeds of 115 mph and a maximum earthquake magnitude of 5, which corresponds to a category 6 on the Mercalli scale. When examining wind load, we also considered our PV panels on the roof. We added ballasted blocks on the racking system to ensure stability during wind uplift. Additionally, ballasted blocks are easier to install compared to penetrating systems, especially with our low slope roof design, and will therefore require less maintenance.

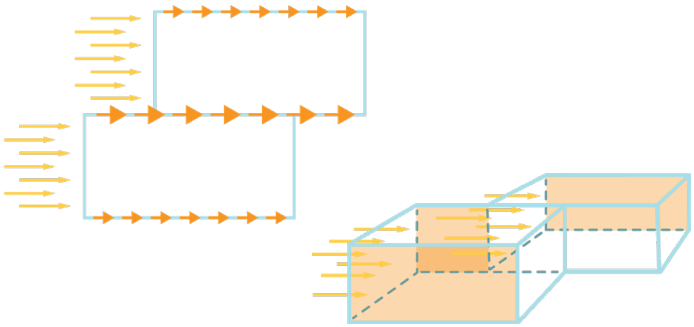

Figure 5: Force visualization from west-east wind loads

When the ground freezes, increasing amounts of ground ice push against the surface, with forces strong enough to crack roads (frost heaving) but as it warms up, the ice thaws and can cause the surface to sink. Any ice that forms under the foundation will cause unnecessary damage and strain on the structure, eventually causing failure. Frost heave is prevented by placing footings below the frost line and we have laid our foundation 3 feet below the surface, consistent with the average Illinois frost line of 36 in. Additionally, rebar is embedded within the foundation for additional reinforcement against cracking concrete.

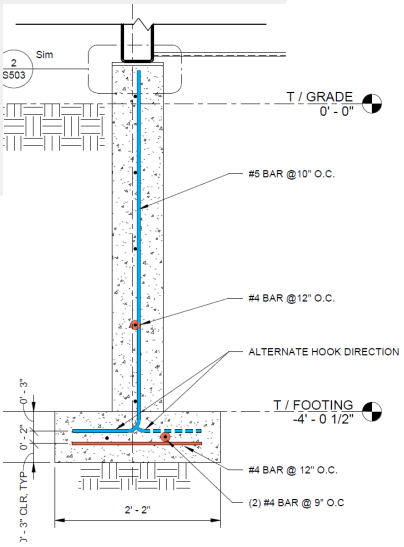

Figure 6: Steel reinforcement in footing

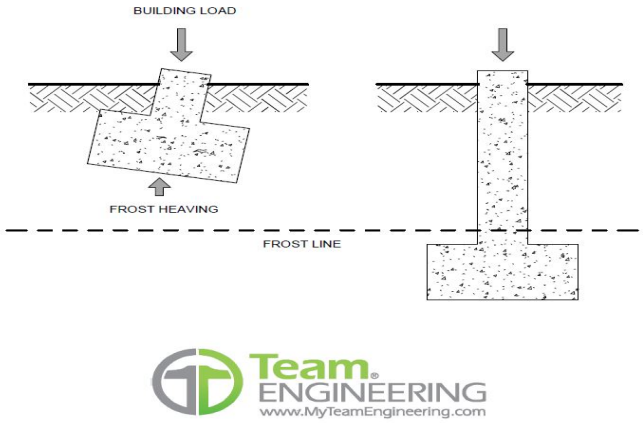

Figure 7: Effects of Frost heaving

From N.Rogers, "Why Meet Frost Depth", Team Engineering, May 30, 2020, https://myteamengineering.com/why-meet-frost-depth/

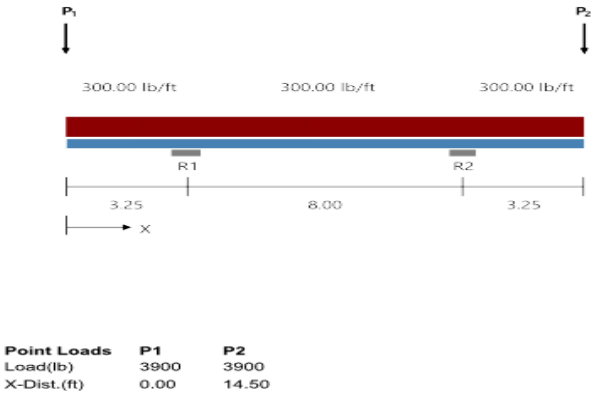

Figure 8: Force calculation of transportation load

For snow loads, after accounting for the base ground snow load in Urbana, IL, its surface roughness category, the slope of our roof, we designed our structure to withstand 30 psf, 10 psf higher than Urbana's average. Our design of open back solar panels also removes the need to account for snow drift as there is nowhere for it to accumulate and cause any eccentric loading.

Another challenge our modules faced was the loads involved in transporting the module from the fabrication site to the on-site build. Due to the nature of modular homes, our design had to account for possible transportation conditions. Wind and acceleration loads significantly affect the structural components of our building. Our method was to strap the model to the bed of the truck, and have the frictional force overcome the wind and acceleration forces. The module also had to withstand the force from the weight of the module onto the truck bed, we found that the 9x5x3/8" HSS rim joists were structurally efficient enough to withstand the force.

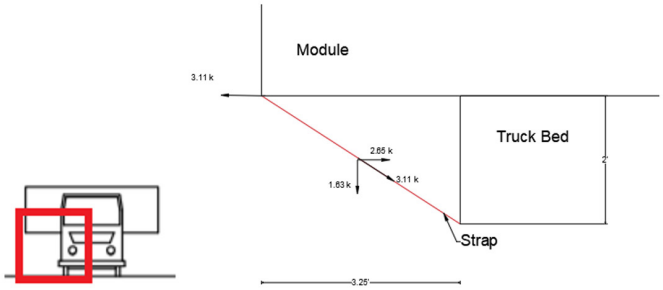

Figure 9: Elevation view of a module attached to the truck bed

When choosing our building's material, we went with the most resilient option, appropriate for our environment. The superior surface finish, high tolerance, concentricity, and straightness made cold-formed steel the best choice for the module. Cold-formed Steel has the highest strength to weight ratio of any structure materials. Cold-Formed Steel is made from a minimum of 25% recycled steel (can be upwards of 70%), 100% recyclable at the end of its life cycle, will not rot, split, warp, or creep over time. Because Champaign has extreme weather conditions, it was

best to use Cold-Formed Steel since the quality does not vary among regions. Our general contractor, Skender, shut down in September due to COVID-19. We had to adapt wood as our structural members, as there were no cold-formed steel contractors near us willing to work.

Landscape

The proposed design introduces a fresh take on residential landscapes in the Midwestern context and hopes to set an example for a productive landscape to surrounding communities. The plant selection is drought resistant, with most of them being resistant to urban pollutants and keeping in mind the high level of salt and pollutants that may pass the site given its location. The native plant communities also require less water than the average garden. As an additional, sustainable, ecological measure and benefit, the home will include its very own greywater system. This will feature a septic tank and aquifer pipes, through which filtered greywater can permeate the surrounding soils and provide an additional reliable water source to the two large western edge-bordering native plant communities on the property. During droughts, this system will further enhance the survival of plants directly surrounding the pipes.

On-site, the planting design, aside from the small food garden, consists almost solely of native plant species, aside from a couple of tall pink phlox varieties and some sod grass varieties for lawn space, all of which are perennials. From Red Osier Dogwood and Indian Grass to Pennsylvania Sedge and Wild Geranium, the native plants help restore more native soil conditions and keep soils healthier and more microbially diverse. The native plants also flower at various times from spring through fall, provide a source of food for native pollinators and small native bird species. The plant communities can provide habitat for additional wildlife, and require minimal maintenance once mature, as they will be mostly self-sustaining. The plant communities will serve as an ecological hotspot within the surrounding urban environments. The aesthetic value of the ecologically-inviting native plant communities is a more than ample garden reward, even during the cold winter months.

Another element of this sustainable landscape is the permeable patio. By allowing excess water to make its way into the natural soil or ground, permeable paving is a sustainable and eco-friendly choice for modern homeowners. Permeable paving can be a prevention tool for flash flooding by absorbing water rather than directing it to drainage or building up on top of the surface. Heat islands are typical in towns and cities because of the amount of land covered by concrete or asphalt paving.

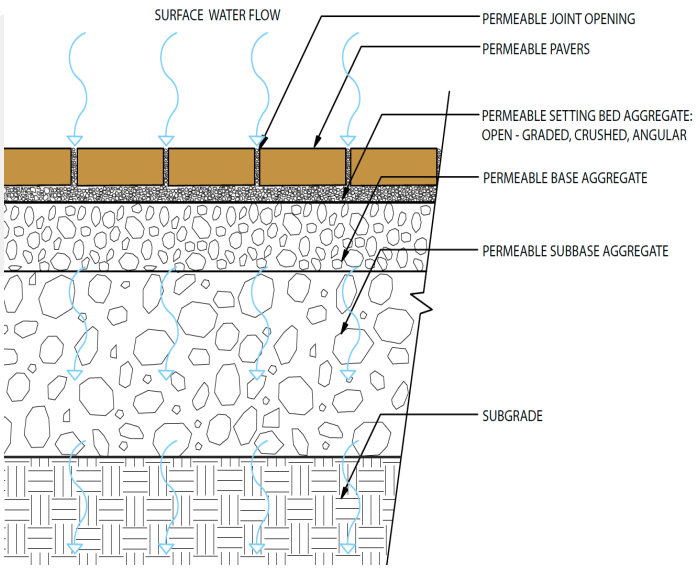

Figure 10: Permeable Cross Section

These surfaces absorb heat, which increases the temperature and causes a heat island effect. If we installed more permeable paving, which allows the soil underneath to breathe, we could reduce heat islands and bring temperatures down.

PV&E

The ADAPTHAUS photovoltaic system is designed to withstand extreme weather and respond quickly to grid disruptions from prevailing disasters. With a 10° tilt, the framing and ballast structure can remain structurally stable across multiple weather conditions. The PV panels have a wide temperature operating range from -45°F to 85°F suitable for Illinois yearly weather conditions. The Li-Ion batteries connected to the system are installed in a weatherproof casing, allowing the battery to resist extreme temperatures that could otherwise cause long-term deterioration.

The Multi-Inverter Modular system connection utilizes one grid-tied SolarEdge inverter and one Outback Skybox inverter connection with two separate arrays of photovoltaic panels. This configuration provides an additional backup should one system fail, the other would be operable without disruptions. The Mission Solar PV panels connected to SolarEdge grid-tied Inverter have power optimizers that double as emergency shutdown systems when the AC power to the system is disconnected. Simultaneously, the PV panels connected to the Skybox inverter have a Fire Raptor Emergency shutdown system installed.

The ADAPTHAUS photovoltaic system switches to grid islanding mode to supply the critical loads when the grid goes offline. The critical loads include the refrigerator, living room lights, plug loads, heat pump, and one small appliance powered via the critical load panel. The switching process is automated through an internal automatic transfer switch (ATS) of Outback Skybox to eliminate the hassle for the homeowners and ensure a smooth transition. The two 5.3kWh 48V DC LiFePo4 batteries (total 10.6 kWh) can supply electricity for about 2 days of daily critical loads of 4.6 kWh. However, the modules connected to the Skybox would still generate power and recharge the battery during off-grid operations. These modules at 3.8kW capacity can generate between 1.2 kWh to 17.4 kWh during winter months and between 3.36 kWh to 24 kWh for the rest of the year. Grid islanding mode has the potential to be indefinite as the modules can generate up to 12kWh per day on average, which accounts for almost 2.6 days of ADAPTHAUS critical loads.

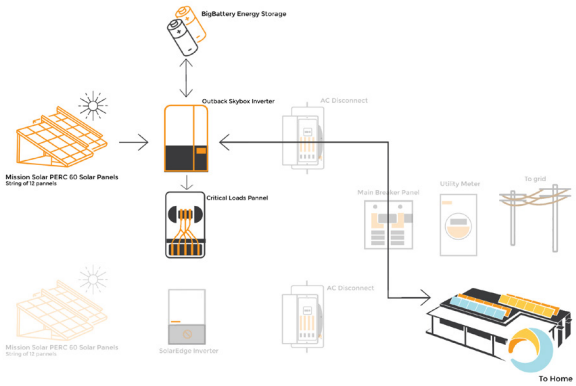

Figure 11: PV System - Offgrid Operation

ADAPTHAUS is installed with a high-efficiency HVAC system, CERV system, LED lights, and highly efficient appliances that use less energy than the minimal code-

compliant buildings. ADAPTHAUS has an annual energy consumption of 7600kWh at 1120 sqft. It consumes 60% less energy than the average Illinois household with the same square footage at 19520 kWh based on 2009 data. The optimizers allow for modular level MPPT tracking to prevent mismatch loss for the modules connected with SolarEdge inverters. The Skybox is always connected to critical loads, but it would also connect to other loads during on-grid operations.

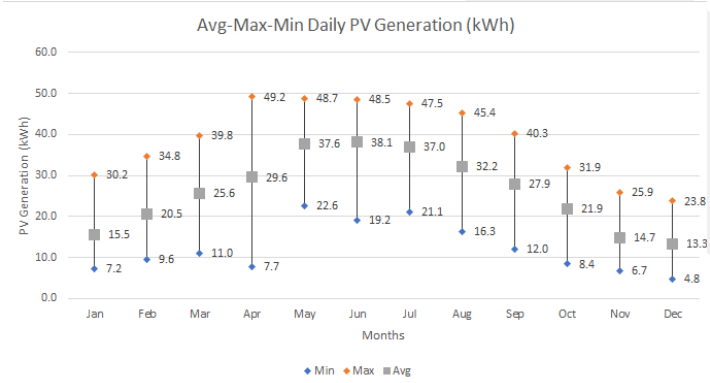

Figure 12: Avg-Max-Min Daily PV Generation (kWh)

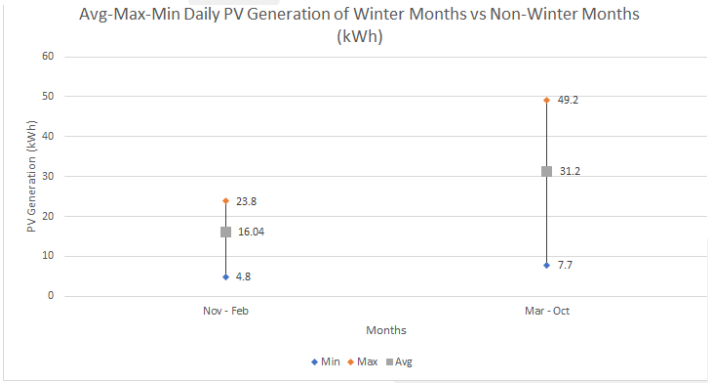

Figure 13: Avg-Max-Min PV Generation of Winter Months vs. Non-Winter Months (kWh)

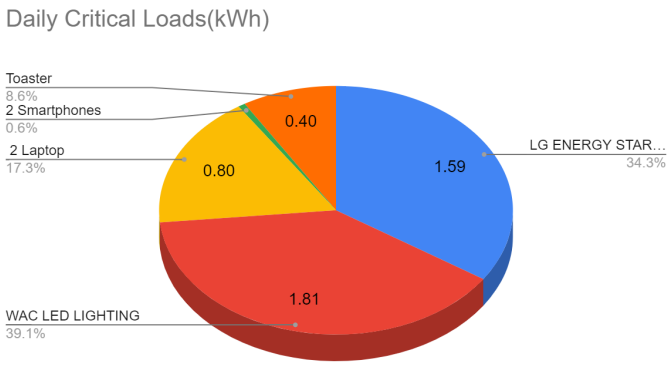

Figure 14: Daily Critical Loads (kWh)

HVAC Integration

The primary targets for HVAC design in resiliency are to ensure the comfort of residents while remaining energy-efficient and being durable to resist extreme weather conditions in the locality. The main components of the HVAC system is a Mitsubishi 12kBtu mini-split system together with an energy recovery ventilator that also has a heating and cooling function (3kBtu capacity). The CERV2 monitors CO2 and VOC levels within the home and ventilates when necessary to maximize indoor air quality and occupant comfort. The higher quality air positively impacts occupants, increasing their productivity, cognitive abilities, and sleep quality.

Our HVAC's main solution during harsh weather conditions such as Frost is having capacity redundancy and being robust. The previous one means our HVAC has the redundant heating capacity, and the latter one is demonstrated by the type of heat pump selected--a type for colder climatic regions. Since a CERV and mini-split are integrated into our design, it is hard

to accurately estimate our system's exact capacity, making it difficult to quantify the extent of robustness we have achieved. However, this equipment makes our system more adaptable. With a mini-split and CERV system, we can easily expand or reduce the system's design depending on the number of modules on the home. Our HVAC system is also resilient because if an added module gets damaged, the HVAC system will still operate.

As for how much less energy is required compared to a minimally code-compliant building, it is assumed that a similar home which is equipped with a traditional ventilation system and the same type of mini-split system is the benchmark for comparison. The design in the assumption is minimally in compliant with Solar Decathlon Building code. Based on the energy simulation result of ZEROs, our HVAC design can save about 14.7% in electricity consumption, with an estimated consumption of 1857.7 kWh a year.

LAHA

Our team has carefully selected appliances and LED lighting fixtures that are energy efficient. The clothes washer and dishwasher also use less water than standard appliances, making them ideal for water shortages.

In particular, the refrigerator comes with customizable energy settings like Eco Mode and Vacation Mode. This can reduce the energy load when the residents are not in the house for an extended period. The fridge also has the Active Fresh Blue Light technology that can keep fruits and vegetables fresh up to 30% longer, which reduces food waste in the kitchen.

The washer and dryer also use impressive technologies to reduce energy consumption. The washer has an automatic water adjustment system that maximizes water efficiency by regulating the amount of water needed for each laundry load. Beko Clothes Washers offer 24% energy savings and 36% water savings compared to other brands. Additionally, the Heat Pump Dryer uses about 50% less energy than conventional dryers. A heat pump dryer uses warmed air to dry your clothes rather than warming up cold air, reducing the energy needed. The dryer also increases its efficiency by using sensor drying instead of timed drying.

Another benefit to efficient appliances, besides water and electricity savings, is durability. We have selected high-quality energy-efficient appliances that are expected to last longer than the average appliance. Beko also recycles scrap metals, paper, plastic, and aluminum in their appliances. This increases the resiliency of the house by improving the overall cradle to grave life cycle and decreases the environmental impact of the appliances during the manufacturing process.